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(54) Improvements in or relating to adaptive filter arrangements.

(57) An extended impulse response characterisitic is obtained by
connecting a plurality of adaptive filters (101) or echo cancelers in
a tandem connection. Delay units (102) are associated with
receive inputs (X) of the adaptive filters or echo cancelers so that
each filter or canceler models a predetermined fixed portion of the
extended impulse response characteristic. The relative positions
of the filters or cancelers in the tandem connection are controll-
ably switched [via 103–0 to 103–(N-1) and (104)] at a predeter-
mined rate (via 105) to ensure so-called 'good' adaptation of the
individual adaptive filters or echo cancelers. The adaptive filter or
echo canceler in a preferred position in the tandem connection
may be allowed to adapt at its normal rate while the other filters or
cancelers are inhibited (via INH) from adapting, or are allowed to
adapt at slower rates dependent on their relative positions in the
tandem connection.

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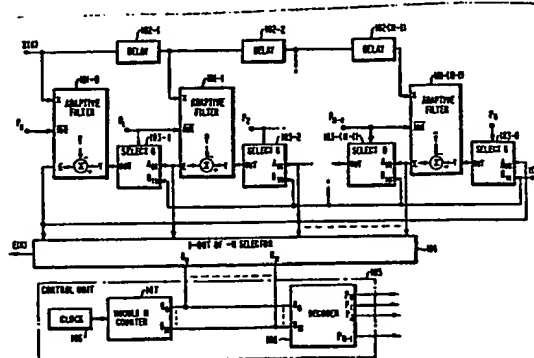
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(K.L.Boyer 1-4)

IMPROVEMENTS IN OR RELATING TO ADAPTIVE

FILTER ARRANGEMENTS

This invention relates to adaptive filter

5   arrangements.

Adaptive filters operate on an incoming signal
to generate an impulse response characteristic in
accordance with a prescribed algorithm. Existing adaptive
filters, for example, those used as echo cancelers, are

10 able to model an impulse response of a limited interval,
for example, 16 milliseconds. In some applications, it is
desirable to model an impulse response having an interval
greater than the available interval of an individual
adaptive filter or echo canceler. One example is in

15 applications where the round trip electrical delay
encountered in a telephone transmission channel is greater
than the impulse response interval of an individual echo
canceler. Another example is in applications for
addressing acoustic delays where the impulse response

20 needed can be extremely long.

One solution to the long electrical delay
problem is to use a "truly" cascadable adaptive filter or
echo canceler. In such an arrangement, each filter or
canceler uses a common error signal to update the impulse

25 response estimate being generated.. In order to do this,
the individual adaptive filters or cancelers must be
arranged to facilitate inputting the common error signal
to the impulse response updating circuitry. Moreover,
only a limited number of these truly cascadable echo

30 cancelers can be cascaded and, therefore, their use
is essentially limited to addressing the long electrical
delays and not the extremely long acoustic delays.

According to this invention an adaptive filter
arrangement includes a first and at least a second

35 adaptive filter arranged in tandem, and means for
controllably switching the relative positions of the
adaptive filters in their tandem relationship to obtain

38 an extended impulse response.

In one embodiment a first adaptive filter or echo canceler arranged to generate a first portion of the extended impulse response interval is switchably connected in tandem with at least a second adaptive filter or echo

5 canceler arranged to generate a second portion of the extended impulse response interval. A switching control circuit is employed to control switching of the relative positions of the adaptive filters or echo cancelers in the tandem connection in accordance with prescribed criteria.

10 The first adaptive filter or echo canceler may be initially connected in a first so-called preferred position in the tandem connection and the at least second adaptive filter or echo canceler including a predetermined fixed delay in its receive side connected

15 in a second position in the tandem connection. A received signal is supplied to the receive side of the first adaptive filter or echo canceler and via the delay to the receive side of the at least second adaptive filter or echo canceler, while a transmit signal is first supplied

20 to a transit input of the at least second adaptive filter or echo canceler and a transmit output signal from the at least second adaptive filter or echo canceler is supplied to a transmit input of the first adaptive filter or echo canceler. A transmit output signal from the first

25 adaptive filter or echo canceler is the initial filter or echo canceler output. Initially, both adaptive filters or echo cancelers are adapting. Upon detection of prescribed filter or canceler output signal conditions the relative positions of the adaptive filters or echo cancelers are

30 controllably reversed, i.e. the at least second adaptive filter or echo canceler including the delay is switched to the preferred position, and the first adaptive filter or echo canceler is inhibited from further adapting and is switched to the second position in the tandem connection.

35 The at least second adaptive filter or echo canceler is allowed to continue adapting.

In another embodiment of the invention an extended

38 impulse response characteristic is obtained by

switchably connecting a plurality of adaptive filters or echo cancelers in tandem, the relative positions of the individual adaptive filters or cancelers in the tandem connection being switched so that each of

5   the adaptive filters or cancelers is connected in a prescribed sequence in a so-called preferred position in the tandem connection. The adaptive filter or canceler in the preferred position may be enabled to adapt at a so-called normal rate while the adaptation rates of the

10   other adaptive filters or cancelers may be controllably set to predetermined rates less than the normal rate of adaptation. The relative positions of the adaptive filters or canceler in the tandem connection may be switched continuously at a predetermined rate. The

15   adaptive filter or canceler in the preferred position may be enabled to adapt at the normal rate while the other adaptive filters or cancelers are inhibited from adapting. The adaptive filter or canceler in the preferred position may be enabled to adapt at the normal rate while the other

20   adaptive filters or cancelers are controlled to adapt at predetermined rates less than the normal rate determined in accordance with the relative positions of the individual adaptive filters or cancelers in the tandem connection.

        The plurality of adaptive filters or cancelers

25   may be switchably connected in a so-called ring configuration and each of the adaptive filters or cancelers may have a predetermined delay associated with a receive input so that each adaptive filter or canceler models a different portion of the desired extended impulse

30   response characteristic. A zero delay is typically associated with one of the adaptive filters or cancelers. Transmit inputs and outputs of the adaptive filters or cancelers may be switchably connected so that the relative positions of the adaptive filters in the ring

35   configuration are controllably switched in a prescribed sequence at a predetermined rate while the portion of the extended impulse response characteristic that each filter or canceler models remains fixed. The adaptive filter or

38   or canceler models remains fixed. The adaptive filter or

canceler in the so-called preferred position of the ring configuration may be enabled to adapt at a normal rate while the other adaptive filters or cancelers may be either inhibited from adapting or permitted to adapt at rates

5   less than the normal rate determined in accordance with the relative position of the adaptive filter or canceler in the ring configuration. The ring configuration may be such that a received signal is supplied via the delay units to receive inputs of the adaptive filters or

10 cancelers while a transmit signal is supplied to the transmit input of the "last" adaptive filter or canceler in the ring configuration. An output from a transmit output of the last filter or canceler is supplied to the transmit input of the next to last filter or canceler

15 in the ring configuration and so on until the signal to be transmitted, i.e. the adaptive filter or echo canceler error signal, is outputted from a transmit output of the first filter or canceler, i.e. the filter or canceler in the preferred position, in the ring configuration.

20   The invention will now be described by way of example with reference to the accompanying drawings, in which:

        FIG. 1 shows in simplified block diagram form a tandem connection of adaptive filters or echo cancelers

25 embodying the invention;

        FIG. 2 depicts in simplified block diagram form details of the control unit in the embodiment of FIG. 1;

        FIG. 3 shows in simplified block diagram form

30 another tandem connection of adaptive filters or echo cancelers embodying the invention; and

        FIG. 4 shows in simplified block diagram form yet another tandem connection of adaptive filters or echo cancelers embodying the invention.

35   Referring now to FIG. 1, a received signal X(k) is supplied to receive input X of

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adaptive filter 10 and via delay unit 11 to receive input
X of adaptive filter 12. Adaptive filters 10 and 12 may
be any one of a number known in the art. In this example,
adaptive filters 10 and 12 are echo cancelers each

5   including an adaptive transversal filter and are of a type
broadly disclosed in U. S. patent 3,500,000 and described
in an article by D. L. Duttweiler and Y. S. Chen entitled,
"A Single-Chip VLSI Echo Canceler", The Bell System
Technical Journal, Vol. 59, No. 2, February 1980, pages

10   149-160. Briefly, each of adaptive filters 10 and 12 has
a receive input (X), transmit input (Y), transmit output
(E), and update inhibit input ($\overline{INH}$) . The adaptive
filters (echo cancelers) operate in known fashion to
generate a signal estimate $\hat{Y}$ which is algebraically

15   combined with a signal supplied to transmit input Y to
generate an error signal at the transmit output E. The
error signal is used internally in the adaptive filter or
echo canceler to update filter tap coefficient values in
order to better model the impulse response characteristic

20   being generated and drive the error signal toward a zero
value.
        Delay unit 11 is employed to fix the portion of
the desired extended impulse response characteristic
generated by each of adaptive filters 10 and 12. The

25   delay interval of delay unit 11 is dependent on the number
of coefficient taps (Z) in adaptive filter 10 and the
sampling interval k being employed. Typically, delay
unit 11 includes a shift register having Z stages which is
clocked at the sampling rate k^{-1}. In one example, the

30   number of taps (Z) is 128 and the sample rate (k^{-1}) is
8kHz. Thus, adaptive filter 10 typically has a zero delay
and models a first fixed portion of the extended impulse
response, for example, a 16 millisecond interval and
adaptive filter 12 has delay unit 11 associated with its

35   receive input (X) and, consequently, models a second fixed
portion of the extended impulse response characteristic,
for example, an interval from 16 to 32 milliseconds.

Adaptive filters 10 and 12 are switchably connected in a tandem connection via controllable selector units 13, 14 and 15. As shown, the transmit output (E) of adaptive filter 10 is connected to the A_{IN} input of

5 selector unit 13 and to the B_{IN} input of selector unit 15. Similarly, the transmit output (E) of adaptive filter 12 is connected to the A_{IN} input of selector unit 14 and to the B_{IN} input of selector 13. A signal to be transmitted, for example, Y(k), is supplied to the A_{IN} input of

10 selector unit 15, to the B_{IN} input of selector unit 14 and to control unit 16. Signal Y(k) is, for example, an outgoing signal to be transmitted in an echo canceler application including near-end speech and the echo signal to be cancelled or an arbitrary system signal in an

15 adaptive filter application. An output from selector unit 15 is supplied to transmit input Y of adaptive filter 12. Similarly, an output from selector unit 14 is connected to transmit input Y of adaptive filter 10. An output from selector unit 13 is connected to control unit

20 16 and is the desired transmit output or error signal E(k). The output from each of selector units 13, 14 and 15 is normally the A_{IN} input and is the B_{IN} input when enabled by a true, i.e., logical 1, switch control signal SW being supplied to the select B input from control

25 unit 16.

Control unit 16 operates to generate switch control signal SW for controllably switching . .
the relative
positions of adaptive filters 10 and 12 in the tandem

30 connection. Control unit 16 in response to an ON-HOOK to OFF-HOOK transition indicating initiation of a call generates a false, i.e., logical 0, switch control signal SW. Upon a prescribed relationship between error signal E(k) and transmit input signal Y(k) occurring control

35 unit 16 generates a true, i.e., logical 1, switch control signal SW. In one example, control unit 16 compares the error signal E(k) power to the transmit input signal Y(k)

power to obtain a measure of the tandem adaptive filter
"advantage" . Specifically, a scaled version of the
transmit input signal power is compared to the error
signal power and when the error signal power becomes less

5   than the scaled transmit input signal power the adaptive
filter in a preferred position in the tandem connection,
initially adaptive filter 10, is assumed to be converged.
At this instant, control unit 16 generates a true, i.e.,
logical 1, SW signal. Consequently, the relative

10 positions of adaptive filters 10 and 12 are controllably
switched, in accordance with an aspect of the invention,
in the tandem connection and adaptive filter 10 is
inhibited from further adapting. This is realized by
selector units 13, 14 and 15 being controlled via signal

15 SW to select input B_{IN} as their outputs and by adaptive
filter 10 being inhibited by signal SW. Thus, transmit
input signal Y(k) is supplied to transmit input Y of
adaptive filter 10, transmit output E of adaptive
filter 10 is supplied to transmit input Y of adaptive

20 filter 12 and transmit output E of adaptive filter 12 is
error signal E(k).

        The reason for switching of the positions of
adaptive filters 10 and 12 is to minimize the affect of
noise generated by the adaptive filters on their

25 convergence. It has been determined that the adaptive
filter in a so-called preferred position in the tandem
connection will converge relatively well and cause
relatively small amounts of unwanted noise. In this
example, adaptive filter 10 is initially in the preferred

30 tandem connection position. Since adaptive filter 10
converges relatively well, it then can be frozen, i.e.,
inhibited from further adapting, and switched to the other
position in the connection while adaptive filter 12 is
switched to the preferred position and is allowed to

35 adapt. Since adaptive filter 12 is now in the preferred
position, it will converge relatively well and the
misalignment noise introduced by adaptive filters 10 and

12 is minimized.

FIG. 2 shows in simplified block diagram form
details of control unit 16. Accordingly, shown are power
value measurement units 20 and 21, amplifier 22,

5   comparator 23 and set-reset flip-flop 24. Transmit input
signal $Y(k)$ is supplied to power value measurement unit 20
which generates an output $Y_p(k)$ representative of the
power of $Y(k)$. Similarly, error signal $E(k)$ is supplied
to power value measurement unit 21 which generates an

10 output $E_p(k)$ representative of the power of $E(k)$. Power
value measurement units 20 and 21 are reset in response to
an ON-HOOK - OFF-HOOK transition. Signal $Y_p(k)$ is
supplied via scaling amplifier 22 to one input of
comparator 23 while signal $E_p(k)$ is supplied to another

15 input of comparator 23. The output from comparator 23 is
negative, i.e., representative of a logical 0, until $E_p(k)$
< $\alpha Y_p(k)$. When $E_p(k)$ becomes less than $\alpha Y_p(k)$ initial
convergence of adaptive filter 10 (FIG. 1) is assumed to
be complete and comparator 23 yields a positive output,

20 i.e., representative of a logical 1. To this end, scaling
factor α is the expected echo return loss enhancement
factor, i.e., the adaptive filter transmit input power
less the adaptive filter output power after, for example,
echo cancellation in an echo canceler application. In one

25 example of an echo canceler application, α is 20 dB power.
An output from comparator 23 is supplied to a set (S)
input of flip-flop 24 when the ON-HOOK - OFF-HOOK signal
is supplied to a reset (R) input of flip-flop 24. In
operation, flip-flop 24 is reset by an ON-HOOK - OFF-HOOK

30 transition to generate a false, i.e., logical 0, SW signal
at output Q. Then, when $E_p(k)$ becomes less than $\alpha Y_p(k)$
flip-flop 24 is set by a logical 1 output from scaling
amplifier 23 to generate a true, i.e., logical 1 SW signal
at output Q.

35 Each of power measurement units 20 and 21
includes apparatus (not shown) for squaring the supplied
input sample values and a low pass filter for obtaining

smooth versions of the desired power measurement values in well known fashion.

One problem with this arrangement is that it must be determined when to switch the filters or cancelers.

5 Another problem is that ON-HOOK, OFF-HOOK information is needed to initiate and reset the filter or canceler adaptation process. This type of information is not usually available for echo canceler applications. Moreover, because of the need to determine when to switch

10 the filters or cancelers, this arrangement is not readily expanded beyond the two adaptive filters or echo canceler applications. Thus, although this tandem arrangement may be satisfactory for some applications, it is not for others, for example, the canceling of acoustic echo and

15 where ON-HOOK, OFF-HOOK information is not readily available.

Referring now to FIG. 3, a received signal X(K) is supplied to a receive input (X) of adaptive filter 101-0 and via delay units 102-1 to 102-(N-1) to receive

20 inputs X of adaptive filters 101-1 to 101-(N-1), respectively. Adaptive filters 101 may be any one of a number known in the art. In this example, adaptive filters 101 are echo cancelers each including an

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adaptive transversal filter and are of a type broadly
disclosed in U. S. patent 3,500,000 and described in an
article by D. L. Duttweiler and Y. S. Chen entitled, "A
Single-Chip VLSI Echo Canceler", The Bell System Technical
5 Journal, Vol. 59, No. 2, February 1980, pages 149-160.
.Briefly, each of adaptive filters 101 has a receive input
(X), transmit input (Y), a transmit output (E), update
inhibit input ($\overline{INH}$)   or an update gain adjustment input
(GAIN) (see FIG. 2). The adaptive filters (echo
10 cancelers) operate in known fashion to generate a signal
estimate $\hat{Y}$ which is algebraically combined with a signal
supplied to transmit input Y to generate an error signal
at the transmit output E. The error signal is used
internally in the adaptive filter or echo canceler to
15 update the tap coefficient values in order to better model
the impulse response characteristic being generated and
drive the error signal toward a zero value.
        Delay units 102-1   to.   102-(N-1) are employed
to fix the portion of the desired extended impulse
20 response characteristic that each of adaptive filters
101-0   to   101-(N-1) generates. The delay interval of
each of delay units 102 is dependent on the number of
coefficient taps (Z) in adaptive filters 101 and the
sampling interval K being employed. Typically, each of
25 delay units 102 includes a shift register having Z stages
and being clocked at the sampling rate K^{-1}. In one
example, the number of taps (Z) is 128 and the sampling
rate (K^{-1}) is 8kHz. Thus, adaptive filter 101-0 typically
has a zero delay and models a first fixed portion of the
30 extended impulse response, for example, a 16 millisecond
interval. Adaptive filter 101-1 has one delay unit,
namely, delay 102-1, associated with its receive input (X)
and, consequently, models a second fixed portion of the
extended impulse response characteristic, for example, an
35 interval from 16 to 32 milliseconds. The next one of
adaptive filters, namely 101-2, in the tandem connection
has two of delay units 102 associated with its receive

input and generates a third fixed portion of the extended
impulse response and so on to the last adaptive
filter, namely 101-(N-1) in the tandem connection which
has (N-1) delay units associated with its receive input

5   and models an Nth fixed portion of the extended impulse
response characteristic.

Adaptive filters 101-0 to 101-(N-1) are
switchably connected in a so-called ring configuration via
controllable selector units 103-0 to 103-(N-1)

10 and 1-out of-N selector unit 104. As shown, the transmit
output (E) of each of adaptive filters 101-0 to 101-
(N-1) is connected to the A_{IN} input of an associated one
of selector units 103-0 to 103-(N-1), respectively,
and to 1-out of-N selector unit 104. A signal to be

15 transmitted, for example, Y(K), is supplied to a B_{IN} input
of each of selector units 103-0 to 103-(N-1). Signal
Y(K) is, for example, the signal to be transmitted in an
echo canceler application including near-end speech and
the echo signal to be cancelled or an arbitrary system

20 signal in an adaptive filter application. The output from
each of selector units 103-0 to 103-(N-1) is normally
the A_{IN} input and is the B_{IN} input when enabled by a true,
i.e., logical 1, signal being supplied to the select B
input from control unit 105.

25   Selector units 103 as shown assume no delay in
the transmit input to transmit output path in adaptive
filters 101. If there are delays in the transmit input to
transmit and output path, appropriate delays need to be
included in 1-out of-N selector unit 104 and selector

30 units 103 to eliminate any resulting transients caused by
instantaneously switching the relative positions of
adaptive filters 101 in the tandem connection.

Control unit 105 operates to generate signals
for controlling the sequential switching at a continuous

35 predetermined rate of the relative positions of adaptive
filters 101-0 to 101-(N-1) in the tandem connection.
To this end, control unit 105 includes clock 106, modulo N

counter 107 and decoder 108. Clock 106 generates a clock
signal at a predetermined rate, for example, at a 10Hz
rate. The clock signal is supplied to modulo N

5 counter 107 which, in turn, generates binary output bits
B_0 to B_M which are representative of binary 0 to
(N-1) in sequence at the predetermined clock rate. In one
example, when the invention is employed to cancel a long
electrical echo, N equals 4 and M equals 1. In another

10 example, when the invention is employed to cancel an
acoustic echo, N equals 8 and M equals 2. Binary bits B_0
to B_M are supplied to 1-out of-N selector 104 for
controlling which one of the transmit outputs (E) of
adaptive filters 101 is to be outputted as the desired

15 tandem adaptive filter output E(K) in the prescribed
sequence at the predetermined clock rate. Binary bits B_0
to B_M are also supplied to decoder 108 which, in
turn, generates control signals P_0 to P_{N-1}.
Decoder 108 is operative to generate a true output, i.e.,

20 representative of a logical 1, in sequence at outputs P_0
to P_{N-1} at the predetermined continuous rate. Only
one of outputs P_0 to P_{N-1} is true at any instant
while the remaining outputs are false, i.e.,
representative of a logic 0. Outputs $\overline{P_0}$ to P_{N-1} are

25 supplied to the inhibit inputs (INH) of adaptive filters
101-(N-1), respectively, and to the select B inputs of
selector units 103-0 to 103-(N-1), respectively.
Since only one of control signals P_0 to P_{N-1} is true
during any clock interval; only one of adaptive filters

30 101 is enabled to adapt
                        while the others of adaptive filters 101
are inhibited from adapting. Additionally, the enabled
one of adaptive filters 101 is connected in a so-called
preferred position, i.e., a first position, in the tandem

35 connection by the corresponding one of selector units 103
being enabled to supply transmit signal Y(K) to the
transmit input (Y) of the last one of adaptive filters 101

in the tandem connection.: Also 1-out of-N selector 104 in
response to binary bits $B_0 - B_M$ selects   the transmit
output (E) of the one of adaptive filters 101 in the first
position as output E(K).

5   By way of example, in a given clock interval
assume P_0 is true and corresponding binary bits $B_0 - B_M$
are representative of binary 0. Then, adaptive
filter 101-0 is enabled to adapt at a so-called normal
rate while the other adaptive filters, namely, 101-1

10   to   101-(N-1) are inhibited from adapting, and
transmit output E from adaptive filter 101-0 is selected
by selector 104 as output E(K). The normal rate of
adaption is a rate obtained by setting the tap coefficient
update gain value so that good quality adaption would

15   result if the adaptive filter or echo canceler was being
used in a non-tandem application. In one example, the
normal rate of adaption is set at -50 dB/second. That is
to say, the decreasing slope of error signal E of adaptive
filters 101 during the initial portion of the adaptation

20   process is 50 dB/second in power. Selector unit 103-0 is
also enabled via P_0 to supply Y(K) to the transmit input
(Y) of the last adaptive filter in the tandem connection,
namely, 101-(N-1). Additionally, the transmit output E
from adaptive filter 101-(N-1) is supplied via selector

25   unit 103-(N-1) to the transmit input of the next to last
one of adaptive filters 101 in the tandem connection,
namely, 101-(N-2) and so on until the transmit signal
modified by filters 101-1   to   101-(N-1) is supplied to
the transmit input of the first adaptive filter in the

30   tandem connection, namely, 101-0. During the next clock
interval P_1 is true and binary bits $B_0 - B_M$ are
representative of binary 1 and, consequently, adaptive
filter 101-1 is switched to the first or preferred
position in the tandem connection and adaptive filter

35   101-0 is switched to the last position in the tandem
connection. Thus, the relative positions of adaptive
filters 101 in the tandem connection are controllably

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switched in the prescribed sequence and at the
predetermined continuous rate so that each one of adaptive
filters 101 is connected in the first or preferred
position in the prescribed sequence. It is noted that
5 since the switching occurs in the transmit inputs and
outputs of adaptive filters 101 and since delay units 102
are connected in circuit relationship with the filter
receive inputs, the portion of the desired extended
impulse response that each of adaptive filters 101-0
10 through 101-(N-1) models remains fixed. Furthermore,
since each of adaptive filters 101-0 to 101-(N-1)
including its corresponding receive input delay is
switched to the first position in the connection, it is
ensured that the impulse response being modeled will
15 correspond to the arbitrary system or that an appropriate
estimate of either an electrical or acoustic echo signal
to be cancelled will be generated.
        Again, the reason for switching the relative
positions of adaptive filters 101-0 to 101-(N-1) in
20 the tandem connection is to ensure "good" adaptation of
the individual ones of adaptive filters 101 and, thereby,
minimizing so-called misalignment noise from corrupting
the resulting error signal E from each filter. To this
end, it is noted that the quality of adaptation of each of
25 adaptive filters 101 is dependent on the relative portion
of error signal E that can be estimated by the adaptive
filter. If the error signal or a portion thereof is
within the portion of the extended impulse response being
modeled by the filter, "good" adaptation results and there
30 is little so-called misalignment noise in error signal E.
However, if none of the error signal is caused by the
portion of the impulse response being modeled by the
particular filter, then the error estimate being generated
will be noisy, i.e., there is a greater amount of
35 misalignment noise generated. Misalignment noise is the
noise on the impulse response estimate being generated
which is reflected in the error signal E after the output

signal estimate $\hat{Y}$ is subtracted from output signal Y.
Allowing the individual ones of adaptive filters 101 to
adapt only when in the preferred position minimizes the
affect of the noise on the overall adaptation process.

5   FIG. 4 shows in simplified block diagram form
another embodiment of the invention. The embodiment of
FIG. 4 is similar to the embodiment of FIG. 3 .
Accordingly, elements in the embodiment of FIG. 4 which
are identical to those in FIG. 3 have been similarly

10   numbered and will not be discussed again in detail.
Indeed, operation of the embodiment of FIG.4 is identical
to that discussed above regarding the continuous switching
at the predetermined rate and in the prescribed sequence
of the relative positions of adaptive filters 201-0

15   to   201-(N-1) in the tandem connection. The
difference between the embodiments of FIG.3 and FIG.4 is
that instead of inhibiting the adaptation of all of
adaptive filters 201 except the one in the preferred or
first position in the tandem connection, the ones of

20   adaptive filters 201 not in the preferred position are
allowed to adapt but at a predetermined rate typically
slower than the normal adaption rate and determined by the
relative positions of the adaptive filters in the tandem
connection.

25   This is realized by controlling the tap coefficient update
gain via control signals G_0 to - G_{N-1} generated by gain
selection unit 209 in control unit 205. The reason for
the varied update gains is that the adaptive filter in the
second or next to the preferred position in the tandem

30   connection is only slightly "less preferred" than the
adaptive filter in the preferred or first position and so
on to the last adaptive filter in the tandem
connection. Consequently, in some applications, it is
preferable to let the "less preferred" adaptive filters

35   still adapt but at a rate slower than the normal or
preferred rate rather than inhibiting adaptation entirely.
Since some adaptive filters and echo cancelers have

selectable update gain, this implementation is readily realizable. To this end, gain control signals G_0 to G_{N-1} are supplied from control unit 205 to the GAIN inputs of adaptive filters 201-0 to 201-(N-1), respectively.

5 As indicated above the normal rate of adaption is a rate obtained by setting the tap coefficient update gain value so that good quality adaption would result if the adaptive filter or echo canceler was being used in a non-tandem application. As indicated above, one example of a normal

10 adaptation rate is -50 dB/second.

The gains of adaptive filters 201-0 to 201-(N-1) are controlled in one example by letting G be the normal update gain value. Then, the gain of the adaptive filter in the preferred position is controlled to

15 be a value G which yields the so-called normal rate of adaption. Then, the gain of the adaptive filter next in the tandem connection is controlled to be G/2 and so on until the last adaptive filter has a gain of G/N. This gain control is realized by employing a read-only-memory

20 for gain selection unit 209 programmed to output the appropriate gain control values G_0 to . G_{N-1} in a prescribed sequence in response to binary bits B_0 to . B_M from modulo N counter 107. Specifically, letting G_i be the gain value for adaptive filter i in the tandem

25 connection (i=0, 1, 2, ..., N-1) G being the normal gain for the adaptive filter in the preferred position and j being the preferred adaptive filter position, then

$$G_i = \left\lfloor \frac{G}{[(i-j) \text{ modulo } N] + 1} \right\rfloor$$

where the symbol $\lfloor \ \rfloor$ is the so-called floor function

30 applied to the function L. (within the symbol) and yields the smallest integer less than or equal to the function L.

The above arrangements are only examples of the invention. It will be apparent to

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those skilled in the art that various changes in form and
detail may be made. Indeed, in Figs 3 and 4 the adaptive
filters or echo cancelers need not be switched
continuously; a number of iterations may only be required.
5 Additionally, echo cancelers may be substituted for the
.adaptive filters as indicated. For example, the
140AB or 140Y echo canceler manufactured by Western
Electric Company may be employed as adaptive filters
101 (FIG. 3) and the 257U or 257AC echo cancelers also
10 manufactured by Western Electric Company may be employed
as adaptive filters 201 (FIG. 4).

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CLAIMS

1. An adaptive filter arrangement including a first (101-0) and at least a second (101-1) adaptive filter arranged in tandem, CHARACTERISED BY means
5 (103,105) for controllably switching the relative positions of said adaptive filters in their tandem relationship to obtain an extended impulse response.

2. An arrangement as claimed in claim 1 wherein the first adaptive filter is adapted to generate a first
10 predetermined portion of the extended impulse response and the second adaptive filter is adapted to generate a second predetermined portion of the extended impulse response.

3. An arrangement as claimed in claim 1 or 2
15 wherein the switching means includes means (105) for switching the relative positions of the adaptive filters at a predetermined rate.

4. An arrangement as claimed in claim 3 wherein the switching means includes means (106,107,108) for
20 continuously switching the relative positions of the adaptive filters in a prescribed sequence at the predetermined rate.

5. An arrangement as claimed in any preceding claim including means (INH) responsive to control signals
25 for inhibiting adaptation of the adaptive filters, and wherein the switching means includes means (108) for generating the control signals to enable adaptation of one of the adaptive filters in a predetermined position in the tandem connection and to disable adaptation of the
30 or each other adaptive filter in the tandem connection.

6. An arrangement as claimed in any preceding claim including means (GAIN) responsive to control signals for controlling the rate of adaptation of the adaptive filters, and wherein the switching means includes means
35 (209) for generating the control signals to control the adaptation rates of the adaptive filters in accordance with their relative positions in the tandem connection.

38 7. An arrangement as claimed in claim 6 wherein

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the adaptation rate controlling means includes means
responsive to the control signal for controllably
adjusting the tap coefficient update gain of the adaptive
filters, and the switching means includes means for
5 generating the update gain control signals in accordance
with prescribed criteria dependent on the relative
positions of the adaptive filters in the tandem
connection.

       8. An arrangement as claimed in claim 7 wherein
10 there are more than two adaptive filters in the tandem
connection, the update gain control signals are
generated so that the update gain of the adaptive filter
in a predetermined position in the tandem connection is
adjusted so that it adapts at a normal rate and the
15 update gains of the other adaptive filters are adjusted
so that they adapt at predetermined rates slower than the
normal rate and determined in accordance with their
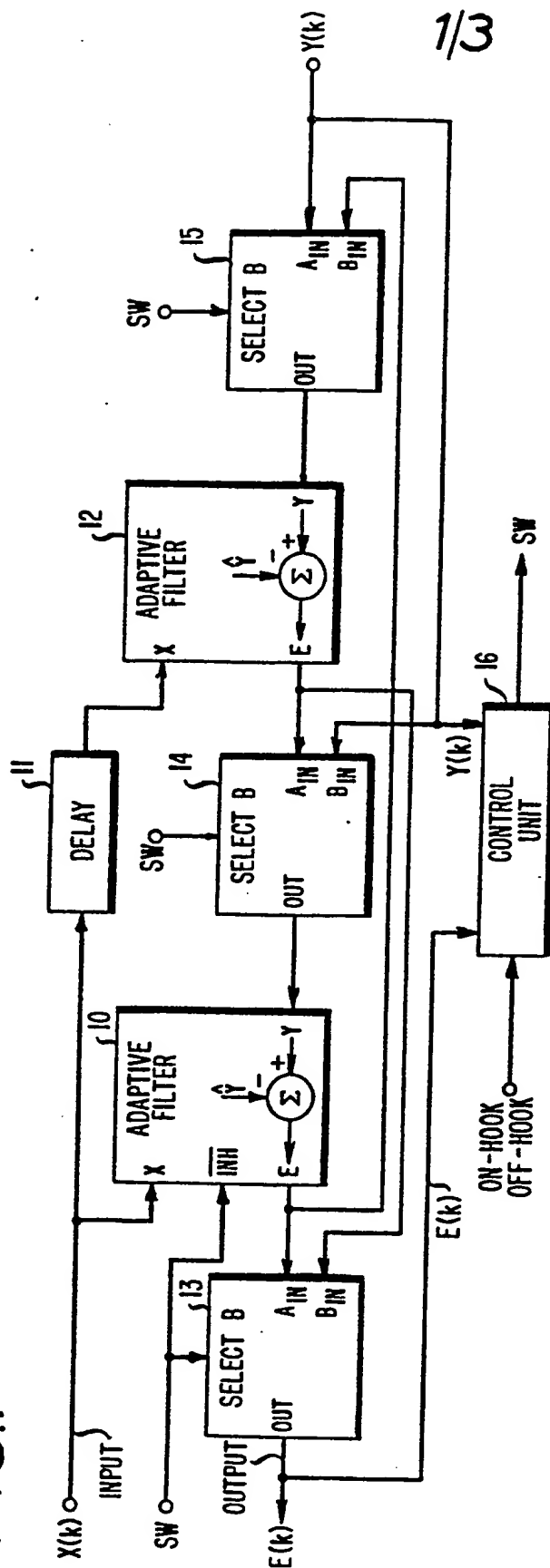relative positions in the tandem connection.

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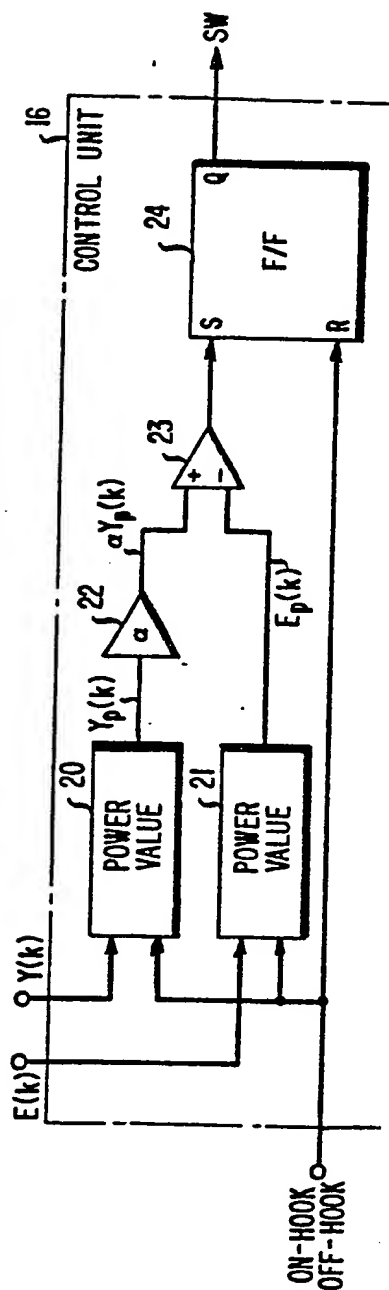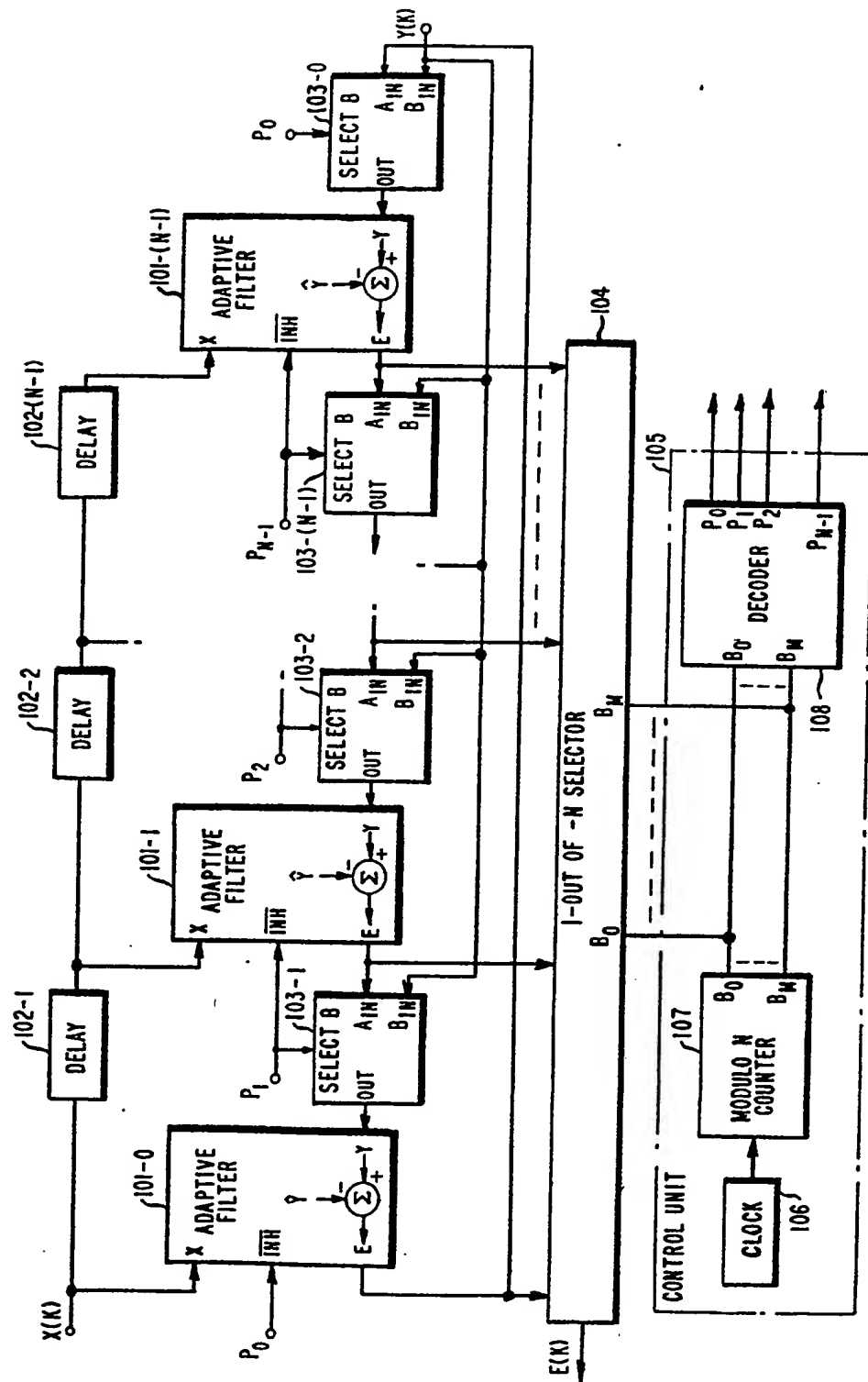011762ε

FIG.1

FIG.2

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FIG.3

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FIG.4